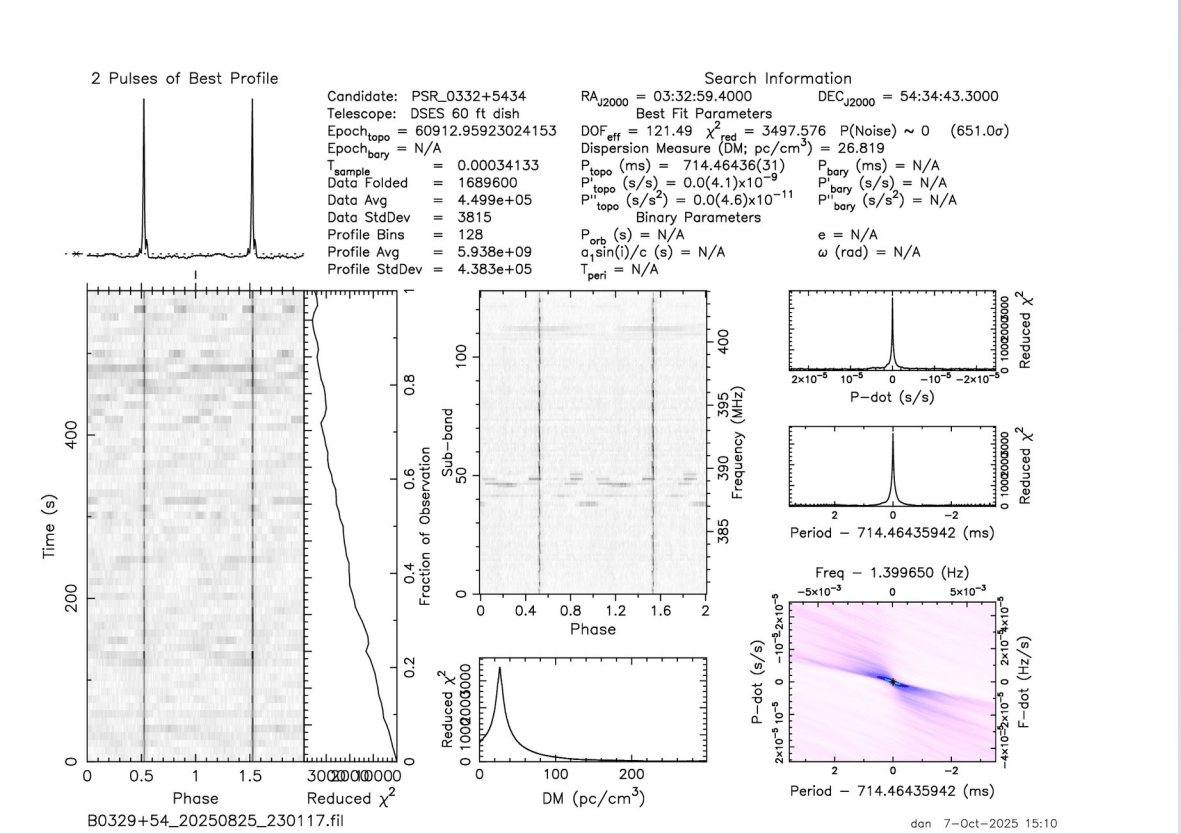
Fishing for Pulsars: Mission Planning

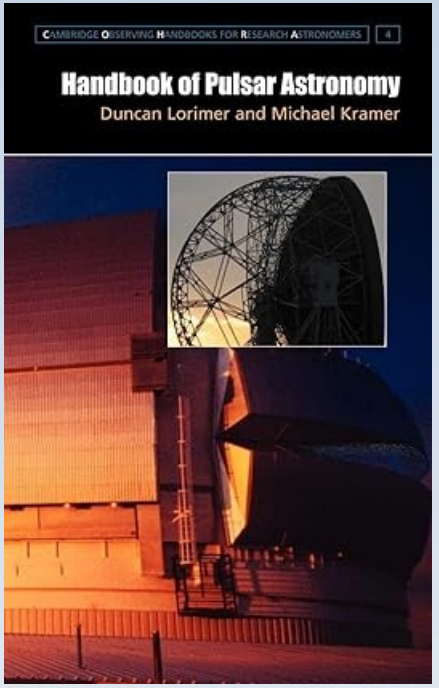


April, 2026

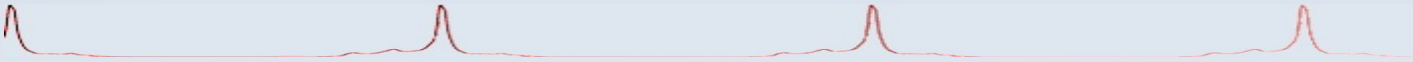
Deep Space Exploration Society

Outline

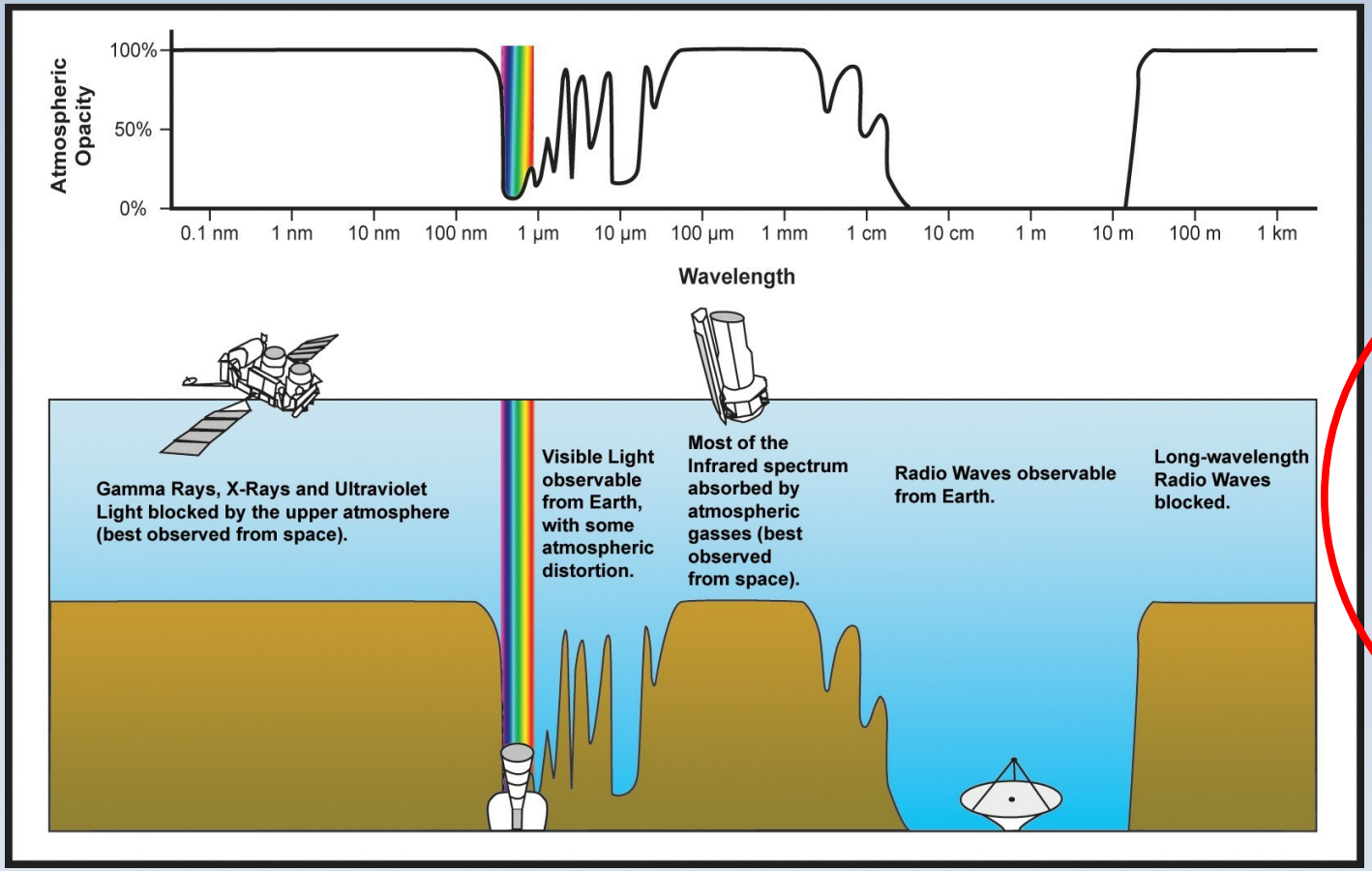
- Pulsar astronomy fundamentals
- ATNF psrcat, Murmur and DSES catalog
- Frontiers to explore
- Parameters for data collection



Reference: “Handbook of Pulsar Astronomy,” Lorimer and Kramer, 2005, Cambridge



Atmospheric Window for Radio Astronomy



The atmosphere is transparent to frequencies from 5 MHz to 30+ GHz

RFI sources include:

External – Sun, FM radio, mobile communications, nav radar, air traffic control, LEO satellites, ham radio

Internal - consumer electronics (Wi-Fi, BT, cell), control room equipment, lights, utilities, pedestal

Goal: minimize RFI; maximize SNR

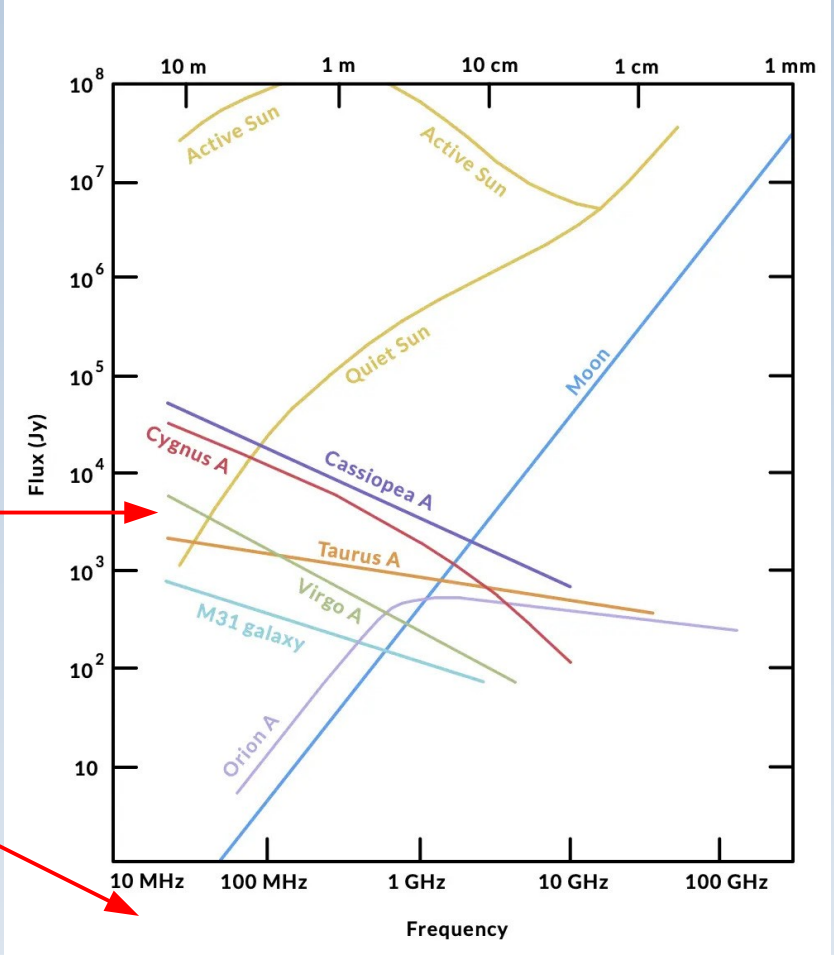
Radio Signals from Space are Weak

Flux density is a measure of signal strength. Units are Jansky (Jy)

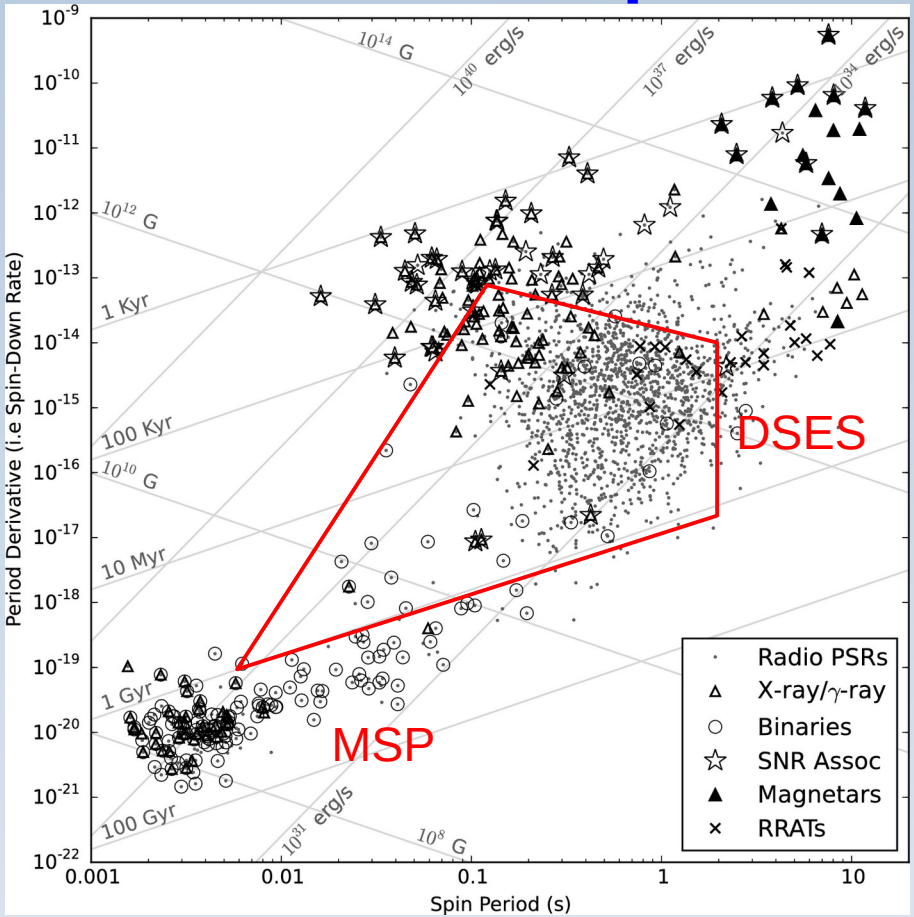
Jy = 10^{-26} watts per meter^2 per Hertz

Supernova remnants in the middle

Most pulsars are in milli-Jansky range. Pulsars are broadband emitters.



Pulsar Properties from Observed P,Ṗ



The PṖ diagram shows properties derived from period (P) and period derivative (Ṗ), including

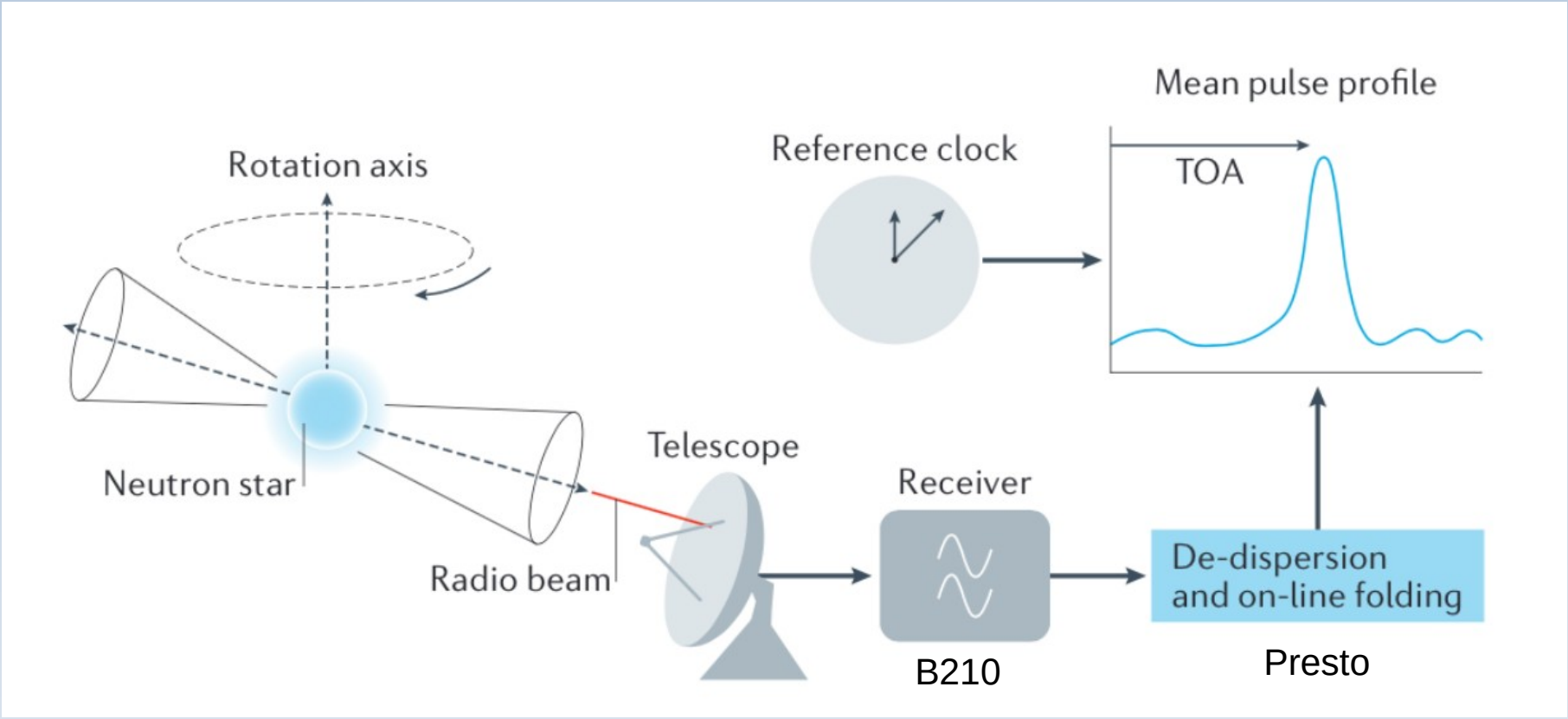
- Characteristic age (not true age)
- Minimum magnetic field strength
- Spin-down luminosity

Highlighted region is where DSES detects radio pulsars

$0.005 < P < 1.9$ seconds

Credit: Essential Radio Astronomy, Condon & Ransom

Pulsar Detection



Credit: “Handbook of Pulsar Astronomy”, Lorimer & Kramer (2005)

Telescope and SDR

- Coordinate feedhorn installation ahead of time
  - Lacking calibration procedures we do bench testing
- Data collection is performed with USRP B210 and GnuRadio via coax feedline from hub
  - GnuRadio generates a filterbank file for post-processing
- System1 Radio Source table contains all pulsars DSES can detect (J2000)

DSES
System Configuration

Plishner 60’ dish, Haswell, CO
- Rubidium clock sync
- 32-core Linux host
- USRP B210 (56 MHz) SDR

Feedhorn	Pol.	LNA	Filter
408 MHz	Lin.	30 db	90 MHz
1296 MHz	Circ.	30 db	30 MHz
1420 MHz	Circ.	35 db	60 MHz

Software Tool	Purpose
I0NAA Murmur, Stellarium	Plan observations
ATNF database	Ephemeris data (.par)
DSES System 1 Dish Control	Dish pointing and tracking
Spectrum analyzer	Calibrate gain, check RFI
GnuRadio 3.10 filterbank	Data recording (SDR)
PRESTO 4.0 with TEMPO	Pulsar detection
RIPTIDE 0.2.4	Pulsar detection
SIGPROC, watutil, Pint	Misc utilities

DSES Pulsar Catalog

#	PSR Name	First Detection	Period (sec)	Pulse Width (ms)	DM	S400 (mJy)	S1400 (mJy)	Feed horn MHz	Int. Time (min)
1.	B0329+54	09-2020	0.714	6.6	26.7	1500		408	15
2.	B0355+54	07-2022	0.156	3.9	57.4		23	1296	240
3.	J0341+5711	12-2024	1.888	43.0	101.0	364		250	90
4.	J0437-4715	08-2021	0.005	0.1	2.6		150	1420	30
5.	B0531+21	08-2025	0.033	2.0	56.7	550		408	60
6.	B0628-28	07-2022	1.244	63.3	34.4		32	1296	60
7.	B0736-40	06-2022	0.375	22.7	160.9		112	1296	90
8.	B0740-28	09-2020	0.167	4.2	73.7	296		408	30
9.	B0833-45	09-2020	0.089	1.4	67.7	5000		408	15
10.	B0835-41	06-2022	0.752	4.4	147.2		35	1296	90
11.	B0950+08	09-2020	0.253	8.9	2.9	400		408	60
12.	B1133+16	09-2020	1.118	5.9	4.8	257		408	240
13.	B1508+55	09-2020	0.739	10.9	19.6	114		408	60
14.	B1556-44	11-2022	0.257	6.5	55.9		37	1296	180
15.	B1641-45	08-2021	0.455	8.0	478.6		300	1420	30
16.	B1642-03	09-2020	0.388	3.4	35.8	393		408	90
17.	B1749-28	09-2020	0.563	6.1	50.4	1100		408	20
18.	B1859+03	11-2022	0.655	9.0	402.0	165		437	180
19.	B1929+10	09-2020	0.227	5.7	3.2	303		408	90
20.	B1933+16	09-2020	0.359	6.0	158.5	242		408	60
21.	B1946+35	09-2020	0.717	19.3	129.4	145		408	240
22.	B2016+28	09-2020	0.558	14.9	14.2	314		408	90
23.	B2020+28	03-2022	0.343	12.0	24.6		38	1296	180
24.	B2021+51	09-2021	0.529	7.4	22.5		27	1420	30
25.	B2111+46	02-2022	1.014	32.1	141.3		19	1296	90

Frontiers to Explore - 1

- Improved timing, sensitivity: What can we detect?
- Millisecond pulsars (MSP are old, stable, binary)
  - DSES fastest is 5 msec (J0437-4715, binary)
  - Pulsar Timing Arrays (PTA) use MSP to detect GW
- Slow period pulsars
  - Slowest is 1.88 seconds. Use time series algorithm, Riptide. Presto was designed to detect msec pulsars

Frontiers to Explore - 2

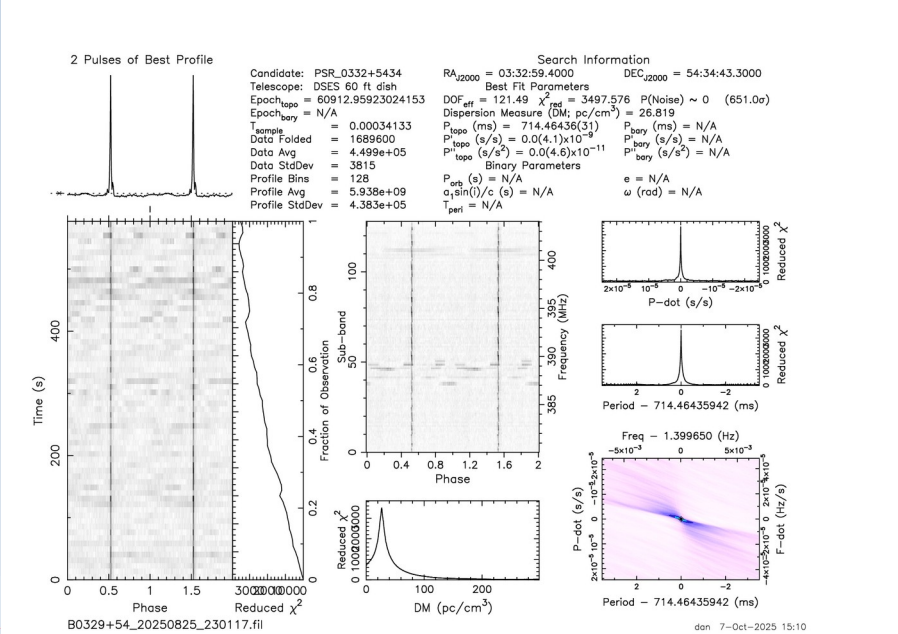
- Fainter pulsars
  - Weakest detection is S1400 = 19 mJy (B2111+46)
- Younger or older pulsars (characteristic age)
  - Most DSES detected pulsars are around 10^6 years old
  - From 10^3 (Crab) to 10^9 years (J0437-4715)
- Closer or more distant pulsars
  - 0.16 < Dist < 7.0 kpc (490 < Dist < 22,831 light years)
  - 2.6 < DM < 478.6 (DM is not distance)

Frontiers to Explore - 3

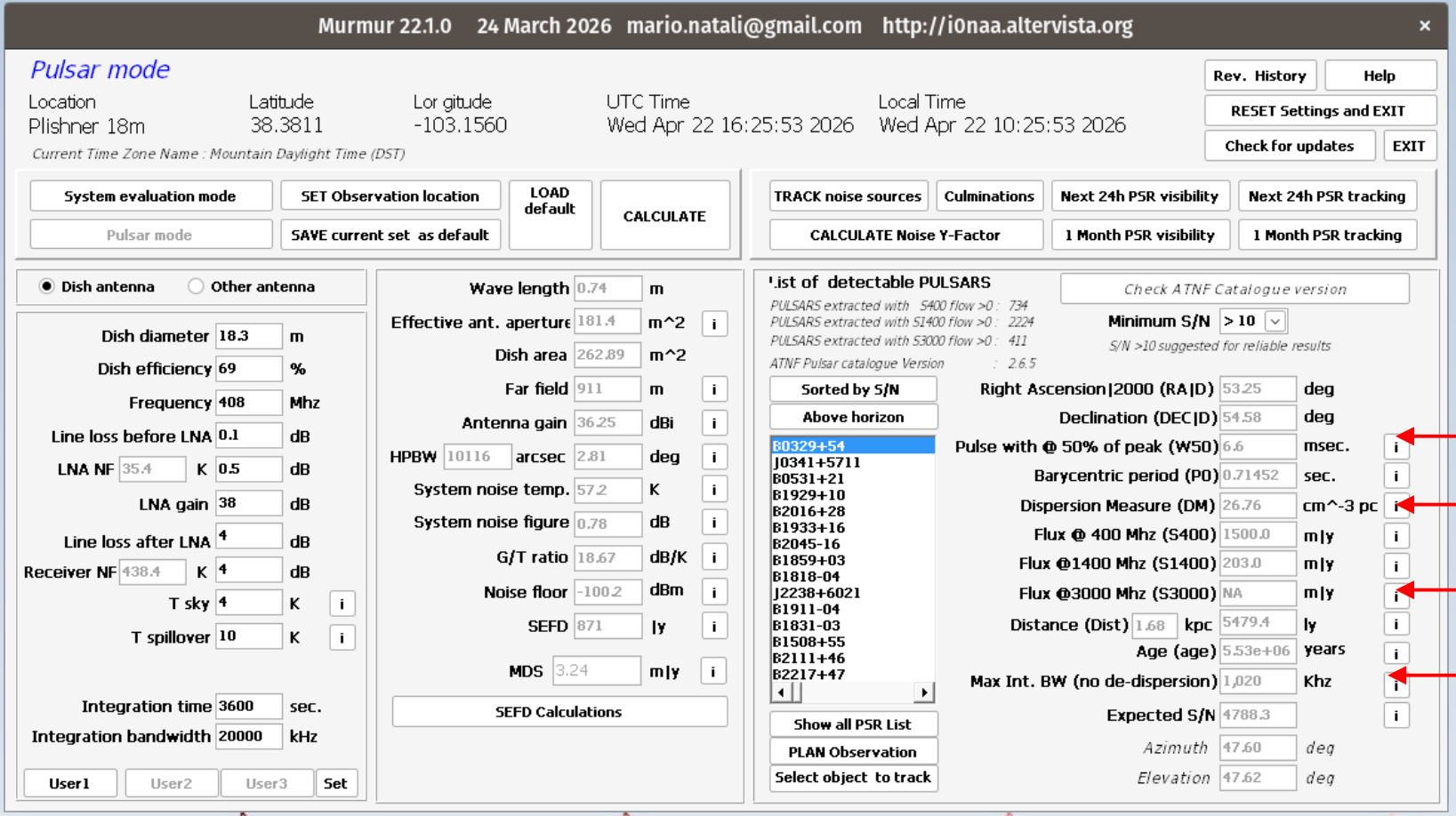
- Repeat observations of same pulsar:
  - ISM scintillation studies, e.g., B0329+54, B2020+28
  - Analyze 3 types of pulses from Crab (see Aug. 2025)
  - Explore astrophysical causes of timing residuals
    - Pulse Time-of-Arrival (TOA) = absolute time
    - Residuals = observed TOA – modeled TOA
    - Causes include instrument effects, pulsar spin-down, etc.
    - Use Rubidium clock (with offset) to calculate pulse TOA
    - > python get_TOAs.py (install Presto 5.0 to fix numpy lib errors)

Where to Start?

- Lacking calibration procedures, start with a 10 minute collection on B0329+54 (might scintillate)
  - Compare previous collections at same frequency



Plan Obs with Murmur and ATNF



W50

DM

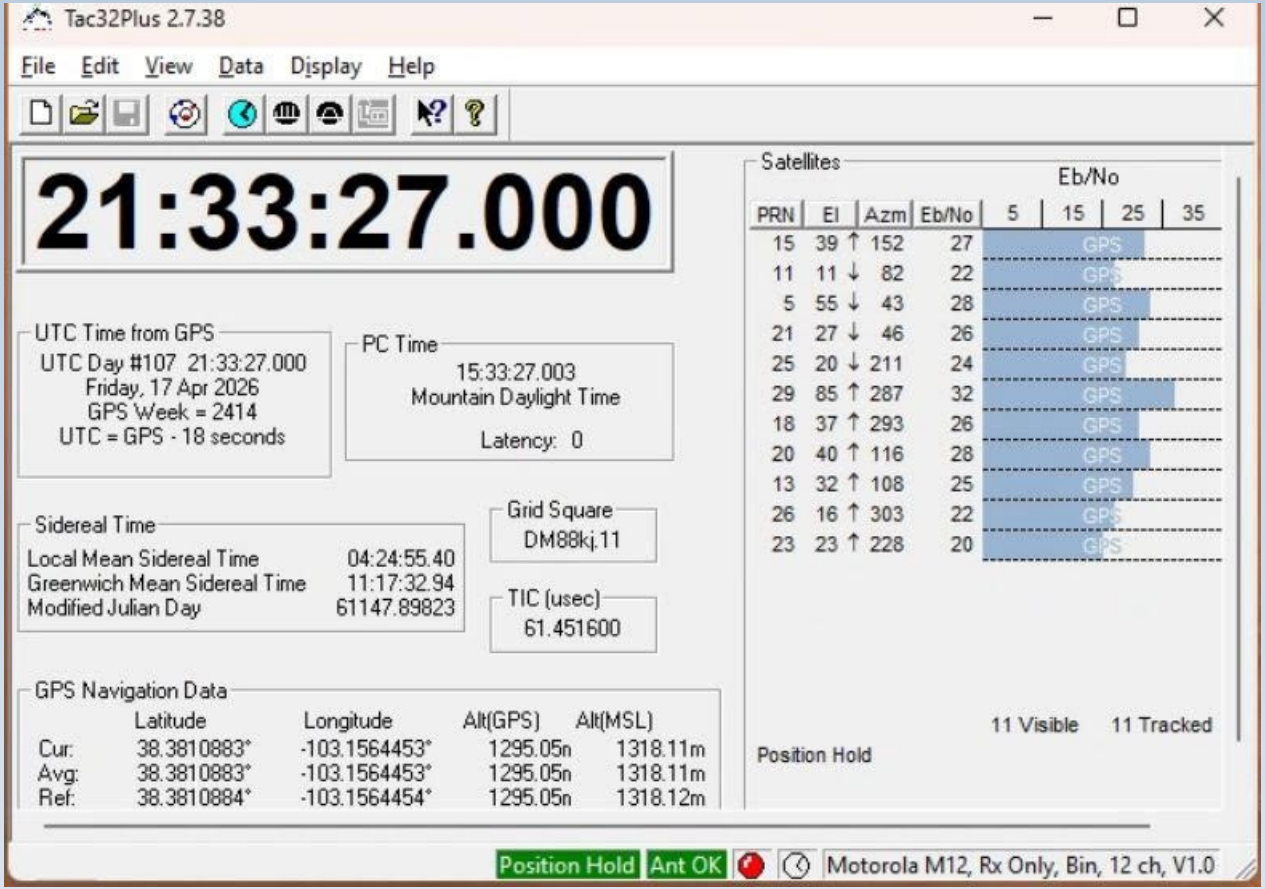
Flux

BW

Demo

- ATNF Pulsar Catalog
  - https://www.atnf.csiro.au/research/pulsar/psrcat/
  - Download psrcat to generate parameters for Presto
- I0NAA Murmur observation prediction
  - https://i0naa.altervista.org/index.php/downloads
- Stellarium to verify pulsar track in sky
  - https://stellarium.org/

Plishner Dish Location



Comparison Websites

- DSES https://dses.science/science-project-overview/pulsar
- K5SO https://k5so.com/pulsars-detected/pulsars_detected_2.html
- OE5JFL https://qsl.net/oe5jfl/pulsar/pulsar.htm
- Neutron Star Group https://sites.google.com/view/hawkrao/neutron-star-group
- EPN Pulsar Profiles https://psrweb.jb.man.ac.uk/epndb/
- Green Bank 20m PSC https://pulsars.nanograv.org/

Preparing for Data Collection

- Select candidate pulsar(s) via Murmur
  - Verify track with Stellarium (avoid Sun)
- Each pulsar sub-directory needs .par and .sh
- Use psrcat to make .par parameter file for post-procesing
  - > psrcat -e -psr psr.txt > psrName.par
  - Verify .par is EPHVER 2, TDB for Tempo
- Edit .sh GnuRadio script parameters (or use GRC)
  - Before pulsar trip: path, pulsar name, RA-DEC, W50
  - At Haswell: gain, center frequency, bandwidth, run time, fbsize

B210 class

GnuRadio Collection Parameters

- Fbsize = # channels. Channel width = bandwidth / fbsize
  - At 1400, DM < 100; Set fbsize so channel width < 0.5 MHz*
  - At 400, DM < 100; Set fbsize so channel width < 0.1 MHz*
  - Check Murmur for max. channel width for each pulsar
- Desired Tsamp ~ 0.1 * W50
  - Based on fbsize, bandwidth, W50, and FFT decimation rate
  - Calculated Tsamp & channel width are printed out at start-up

* “The Handbook of Pulsar Astronomy,” Lorimer and Kramer, 2005, p. 109

Edit Filterbank Parameters in Script

- Run time (seconds)
- Path
- Pulsar name
- RA-DEC
- W50 (sec)
- RF Gain
- Center Freq (MHz)
- SDR bandwidth (MHz)
- Fbsize

- ATNF .par file name

Open

runPulsar_B0329+54.sh
/data1/Pulsar/data22/July24/B0329+54

```
12
13 # Set pulsar filterbank parameters
14 # max 16 char for source. dec = hms. ra = dms.
15 numIter=1
16 single_runtime=3600
17 path='/data1/Pulsar/data22/July24/B0329+54/'
18 sourceN='B0329+54'
19 ra=033259.40
20 dec=543443.30
21 pw50=0.0066
22 rfgain=64
23 freq=1300e06
24 samp_rate=30e06
25 fbsize=512
26
27
28 # prepfold params. Set nCPU = 1/2 total
29 nCPU=2
30 cd $path
31 parFile="${path}J0332+5434.par"
32 if [ ! -s "$parFile" ]
33 then
34     echo "runPulsar error: $parFile not found."
35     exit 1
36 fi
37
```